Electric Motor Reliability
The Core Problem

1 in a Series
The Dreisilker Electric Motor Repair Learning Center

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Abstract: The debate concerning the impact of electric motor repair is again coming to a head. From the impact on the environment brought up by the US EPA in 2010 to the discussion of impact on efficiency, mechanical components and machine reliability over the last decade, attempts to derail the arguments against improper repair practices are again pressed strictly from a public relations standpoint. Numerous independent studies performed over four decades indicate problems through the motor repair process. The counter has been to present a study that supports the conclusions of those studies, but is used, instead, to give credence to improper practices. In this paper we will focus on the issue of the copper removal practice and impact on the core through the electric motor rewind process including the impact on electric motor reliability and the environment.

Introduction

With constant pressure to improve electric motor efficiency, as well as design pressure to provide more power in smaller packages, the materials used in the manufacture of electric motors continues to improve. With this, the design of electric machines have tightened, pushing some limits, and an industry sees this as an opportunity to push the limits in order to increase the speed of the repair process. The result, in the first case, is the tendency of some manufacturing companies to fall short of best practice and introduce design issues that impact reliability. The result, in the second case, is for the electric motor repair facility to push the limits too far while improperly citing studies resulting in motors that do not operate as designed and have decreased their reliability.

Figure 1: Mechanical Stripping Stator

Every independent study, including a few that are not really independent, cites, correctly, that a motor repair performed correctly has a limited impact on the efficiency and reliability of the electric motor. The proof related to limited impact is normally a repair performed under scrutiny, usually without serious cost constraints, with step by step review of the process. The results, in each case, were limited impact on the capability of the machine to operate as designed. Yet, blind studies performed where motors are sent to repair shops are returned with some to severe reduction in efficiency and, as a result, reliability.

Can it be that it is possible to perform a repair in such a way that no significant damage occurs but that the industry is either uninformed or not caring enough to perform the repairs to that level while quoting a study that requires the repair to be performed at near-laboratory standards? In one blatant case, a repair shop discusses quality repair practices on YouTube® while showing images of mechanics using torches on windings and a temperature passing 800F on a burnout oven. Are these repair shops playing upon the ignorance of the impact of poor repair practices on the general public while continuing to do 'business as usual?'

Figure 2: Stator Processed in a Burnout Oven

The primary argument revolves around the impact of such things as the impact of burning out the core in an incinerator to remove copper with additional concerns around changing wire, winding design, and other modifications to the original design. While it is known that some changes will have a positive impact on the post repair life of an electric motor, a majority of the changes that are implemented with the purpose of making the repair faster or easier do not have a positive impact on the reliability of the motor.

More recently, the US EPA brought the use of burnout ovens to the forefront as part of a regulatory move on such devices in order to reduce their harmful effect on the general public's health.[1] The response to the act by the US EPA was to strong-arm the organization in relation to the impact on the economy, threatening that removing the ability of motor repair shops to use burnout ovens would 'cripple the economy,' and that there were no other practices to take the place of burnoff ovens. There was not one single argument put forth suggesting that the use of burnout ovens would not impact human health and the environment. Due to time constraints set by the courts and legal posturing, the US EPA had to implement the regulations, but leave burnout ovens as *excluded* from the existing regulation.[2] The industry attempted to state that they were *exempted*, which would indicate that there were no harmful effects and that they did not require regulation.[3] In the arguments put forth in the US EPA ruling, they specifically state the opposite but that the regulation must meet the court-set release date and that it was important that the issue related to burnout ovens must be included in another set of regulations.

Figure 3: Stator Processed with Mechanical Stripping

The Studies

One of the earliest published studies on the impact of stripping processes on the core was published in a paper entitled "The Motor Rewind Issue – A New Look,"[4] and focused on the impact of the repair process on the core of the motor with details on the overall impact of motor efficiency. While this was not the first discussion related to the topic of the impact of repair practices on motor efficiency, it was the first that provided an actual study on the pre and post

[1] US EPA, 40 CFR Part 60 Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources; Commercial and Industrial Solid Waste Incinerator Units; Proposed Rule, Federal Register, Part 4, June 4, 2010

[2] US EPA, 40 CFR Part 60 Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources; Commercial and Industrial Solid Waste Incinerator Units; Final Rule, Federal Register, February 21, 2011

[3] EASA, Ruling Favors EASA Members; Burn-Off Ovens Exempted, http://easa.com, February 25, 2011.

[4] Montgomery, David C., "The Motor Rewind Issue – A New Look," IEEE Transactions on Industry Applications, Vol. IA-20, No. 5, September/October 1984

core loss impact on burnout ovens. While the impact of burnout ovens was empirically studied, as with future projects, the alternate processes, such as mechanical stripping, was addressed, but not from a study standpoint, but from an opinion standpoint. I should repeat that: in every study, starting with this one, when it is discovered that burnout ovens have a negative impact on core loss and motor efficiency through empirical methods, attempts at explaining away alternative methods are strictly editorial and not supported by experimental fact.

During the 1990s, while energy efficient motors were being marketed through national energy programs throughout most of the world, preparing users for upcoming regulations, the theme of the impact of motor repair on motor efficiency became fairly common. A series of studies were undertaken to determine the impact of the repair process on efficiency in Canada with the results being adopted by the US Department of Energy, often to the consternation of the electric motor repair trade association.

Canadian Studies

The first of the studies was published in 1991 by Ontario Hydro.[5] It consisted of an experiment in which nine of ten identical 20-horsepower standard efficient motors were rewound. The nine motors were identically failed and then sent, blind, to nine separate electric motor repair facilities throughout Canada. When they were returned, they were analyzed for efficiency impacts. It was found that the average loss of efficiency was in the area of 1.1% with the maximum reduction around 3.4%. The increase in core losses ranged from 2.2% to 46%. It was also determined that the reduction in efficiency is cumulative, meaning that the increase in core loss and reduction in efficiency increases each time the motor is repaired.

In 1993, BC Hydro published another rewind study using energy efficient electric motors.[6] In this case, eleven 20 horsepower motor were used, with ten being failed and sent for repair. Unlike the Ontario Hydro study, the average decrease in efficiency was 0.5%, with the most significant reduction being due to improper bearing replacement. There were relatively small decreases in efficiency due to core loss and some due to changing I^2R losses, as a result of changes to the cross section of wire during the repair process.

Due to the significant differences between the 1991 and 1993 studies, the Canadian Electrical Association (CEA) commissioned the Hydro Quebec Rewind Study, which was compiled by Demand Side Research of Vancouver, BC. The result was the booklet, "Evaluation of Electric Motor Repair Procedures Guidebook (CEA 9205 U 984),"[7] which outlined the findings. In this study, the coils of a number of energy efficient motors were removed by several different methods (burnout oven and mechanical stripping – Dreisilker/Thumm method) and were rewound. The process was repeated three times per motor with a CSA Standard 390 energy efficiency test (equivalent to the IEEE Std 112 Method B) performed after each rewind. It was shown that no significant loss in efficiency was detected through all three rewinds (less than

[5] Penrose, Howard W, "Anatomy of an Energy Efficient Electric Motor Repair," IEEE Electrical Insulation Magazine, IEEE Dielectrics and Electrical Insulation Society, February, 1997.
[6] Penrose, "Anatomy of an Energy Efficient Electric Motor Repair"
[7] Demand Side Research, Evaluation of Electric Motor Repair Procedures Guidebook: CEA 9205 U 984, Canadian Electrical Association, 1994

0.2%). However, in order to achieve this, a number of quality control steps were required to be followed.

The CEA study noted, in particular, that there were significant emissions through the burnout oven method that did not exist with the mechanical stripping method. It was again mentioned that even though it was not observed, and the process was not performed correctly, that somehow mechanical stripping would do damage. However, no matter how hard the operators tried in the study, they were unable to actually damage the stators being stripped using the Dreisilker/Thumm process. In both core loss and efficiency testing the mechanical stripping method showed either no change or slight improvements over the entire study, whereas burnout ovens showed an impact even when strict processes were followed. Members of the motor repair trade association suggested that the caution remain in the study because of the 1984 paper, which, in effect, meant that there were attempts at conclusions that were not scientifically observed. The object appeared to be more of a distraction from the scientifically observed facts that significant emissions, increases in core losses and damage were observed using the burnout method.

It was also noted that only one stator at a time could be burned out in the burnout oven as reducing the core loss damage to the stator core required significant temperature control and the oven both required a temperature sensor being affixed to the stator core and an active water suppression system. It was noted that the air temperature within the burnout oven varied significantly and spot temperatures in the stator itself averaged from 100F to 150F higher than the air temperature in the oven. This becomes significant as most repair facilities fill ovens with stators far surpassing the number of contact sensors available.

It is also worth noting that the CEA study was initially heavily supported by the motor repair trade association. Once the conclusions were published it was no longer cited in any future documentation or listing of studies published by the association.

<u>EASA/AEMT Study</u>

There are a lot of statements that are attributed to this study ranging from anti-mechanical process statements through stators being able to be burned out at excessively high core temperatures. In virtually every case, these statements are untrue and not attributable to this study.

"The Effect of Repair/Rewinding on Motor Efficiency: EASA/AEMT Rewind Study"[8] was performed by trade associations overseeing the motor repair industry under carefully controlled repair processes. In fact, the conclusions are not that much different than those found by the CEA study. Published in 2003, the study makes the same cautions and considerations outlined within this paper. It reviewed only the burnout oven process and reviewed the overall efficiency of the electric motor and related impact as well as taking a look at the changes to core losses using commercial core loss testers. Overall, there is excellent information outlined within the study related to how a motor repair should be performed.

[8] <u>The Effect of Repair/Rewinding on Motor Efficiency: EASA/AEMT Rewind Study</u>, EASA/AEMT, 2003

However, no part of the study included empirical tests using any methods other than burnout for coil removal. In the section related to the use of burnout ovens and temperatures, the study does spend a tremendous amount of time discussing the dangers of allowing oven temperatures to become too hot and puts specific limitations on the temperatures based upon the kind of steel and inter-laminar insulation. Additionally, there are cautions about allowing the laminations to splay (separate from the others) which is a concern observed during the study.

While the author has heard claims by other repair facilities that the EASA/AEMT study specifically says that mechanical stripping processes harm the stator core, it must be noted that there are no such claims or performance within the study, itself. It is not mentioned in any way, shape or form, and those companies rely upon the end user not reviewing the study. In fact, we highly recommend that the study is reviewed.

The study did note that changes to recommended practices will impact the efficiency of the electric motor.

Additional Study Comments

In 1995, the Bonneville Power Administration published a study entitled, "Industrial Motor Repair in the United States."[9] The study was both revealing and disturbing.

"Only one-third of the shops used written quality assurance standards of any type and were familiar with quality assurance procedures. Testing practices vary widely from shop to shop. Testing was most often used as a diagnostic tool for troubleshooting. Although insulation, winding resistance, vibration and core loss testing should be done routinely as part of a quality repair, only insulation resistance was done regularly."

In addition to testing issues: "Forty-two percent of the shops reported problems winding motors with original size wire because of insufficient room in the slots and the unavailability of the correct wire sizes. Eighty-one percent of the shops reported that they changed winding configuration because of equipment limitations or shop preference. Several shops also reported difficulties with bearing replacements because they had difficulty obtaining specifications and special and sometimes proprietary bearings."

"Of the quality assurance procedures shops used, 40 percent were repair procedure specifications, 25 percent were test specifications and 21 percent were EASA standards. Only one of the 65 shops responding used any form of quality assurance testing."

The primary conclusion of a majority of the motor repair studies was that a motor repair shop must follow consistent standards and must perform to a specific level. The challenge with this became apparent during the 2013 motor repair trade association meeting where, as reported by Electrical Apparatus Magazine in August of 2013,[10] most motor repair shops responded

[9] Schueler, Leistner and Douglass, Industrial Motor Repair in the United States, Bonneville Power Administration, US Department of Energy, 1995.
[10] "Report on the 2013 EASA Conference," Electrical Apparatus Magazine, August, 2013

negatively to a proposed certification process to verify that they were following industry standards.

The Relationship of Efficiency and Reliability

Considering that the vast majority of repair shops that are performing burnout oven rewind repair do not have core loss test equipment, nor perform hot spot testing, the question is raised: what is the impact on the expected life and reliability of a motor through the repair process? The impact is easily discussed through the impact of repair on efficiency as modifications to the components that make up the reliability of a motor can be easily measured through the motor efficiency.

<u>Allowable Repair Core Losses</u>

Although it is suggested by the studies supported by the repair industry trade association that there are no impacts on the stator core, all of the information, including the EASA/AEMT study indicate that there can be an up to 20% increase in core losses between the before and after core loss tests. These are the tests performed before and after stripping the copper out of the stator. While this is confusing, as it should be, let us assume that this increase stays at the 20% increase, which is outlined as ‘no increase in losses.’

In a paper entitled, “The Impact of Traditional Motor Repair Practices on Energy and Environment Including Meeting the Minimum Requirements of IEEE 1068-2009,”[11] the average decrease in efficiency was 0.3% per repair. This is usually undetectable, but often is the result of a breakdown in the inter-laminar core insulation which generates hot spots during operation.

<u>What’s Really Found in the Field</u>

Based upon the paper above, with the cited 150 horsepower electric motors, the increase of 1 amp of current draw, a minor increase compared to most, would indicate an increase in core losses of 97%! With losses almost doubled in the core, the heat generated would significantly impact the expected life of the insulation system and/or limit the motor’s horsepower significantly. Unfortunately, it is not unusual to find increases in operating current significantly higher than one amp across all motor sizes that are processed in a burnout oven.

However, also based upon the studies, this increase in current draw also extends to other improper repair practices from altering wire size during rewinding to improper bearing replacement. Unfortunately, the focus is pushed in this direction and not in the direction of the other permanent damage done to the machine.

The result of improper repair practices is readily found in a study performed by Advanced Energy and their reporting of an internal study on motor repair by Weyerhaeuser in which it was reported that while 50% of new motors would last up to seven years, 50% of repaired motors only survived three years.

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[11] “The Impact of Traditional Motor Repair Practices on Energy and Environment Including Meeting the Minimum Requirements of IEEE 1068-2009,” Plant Services Magazine, http://www.plantservices.com/articles/2010/12motorrepairpractices/

The "Achieving More with Less," report also states: "In view of the huge costs associated with downtime, motor reliability is not considered one of the most important factors in repair versus replace decisions. However, actual in-plant data on motor reliability is sparse. The goal of this project was to obtain in-plant historical motor data for the purpose of estimating the mean time between failure (MTBF) of new and rewound motors."

Conclusion

This paper is the first in a short series on the impact of motor repair practices on plant reliability, energy and environmental impact. The purpose was to outline some of the studies and concerns related to electric motor repair, in particular the rewind process, and what the impact is of traditional motor repair practices.

One of the most significant challenges is that only a small minority of the motor repair industry is pressing for changes and improvements. The motor owner is usually unaware of the impact of traditional repair practices on their motor and the resulting impact on machine reliability and environmental impact. The chief concern, in both cases, is that the industry, as a whole, has not advanced much in over a century, and that improper repair practices and short cuts, even when knowing better, have a huge impact on the profitability and reliability of the plant or system they are operating in and a negative impact on community health.

Biography

Howard W Penrose, Ph.D., CMRP, is the Vice President of Engineering and Reliability Services for Dreisilker Electric Motors, Inc., the Web-Editor-in-Chief for the Institute of Electrical and Electronics Engineers, Inc.'s Dielectrics and Electrical Insulation Society and the Outreach Director for the Society for Maintenance and Reliability Engineers. Dr. Penrose is an Electric Motor Repair Journeyman, Certified Maintenance and Reliability Professional, and numerous other industry and professional certifications. He received five UAW/GM People Make Quality Happen Awards for energy, environment and motor management programs. Dr. Penrose also represents the United States and a WPC/AWPC Master Powerlifter.